Momentum, Vorticity, and Mass Fluxes at SandyDuck

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LONG-TERM GOALS

To characterize nearshore flows as a function of the forcing conditions: fluxes of mass, momentum, vorticity, sediment transport, etc., for given wind, wave, and offshore conditions.

OBJECTIVES

The objectives of this project are to: (1) understand and quantify the quality of data from "Phased-Array Doppler Sonar" (PADS) systems in the shallow water environment near shore; (2) classify the observed circulation conditions in terms of wave height and direction, wind strength and direction, mean flow strength and direction, and variability; (3) make the interesting segments of data available over the internet; (4) begin integrating the data into models of the nearshore hydrodynamics.

APPROACH

Two "Phased Array Doppler Sonars" (PADS) were deployed in SandyDuck and operated over September and October, 1997. Sound was projected over a 90°-wide horizontal fan, scattering off particles in the water and the bottom. The backscattered signal was digitally beamformed into returns from discrete directions and analyzed for Doppler shift. The time-delay after transmission translates to distance. Thus, each PADS provided data over a "pie" up to 400 m radius by 90°, with 8 m radial by 7° angular resolution (see figure 1). In the overlap region, both horizontal components of flow are estimated. The data resolve both surface waves and lower frequency currents. This extensive coverage is attractive for the study of wave–current interactions, if the data can be verified and calibrated.

PADS data were compared with independent measurements made at several locations. Near-bottom currents were provided by S. Elgar et al. (WHOI and SIO) and A. J. Bowen et al. (Dalhousie). At one location, low-frequency current profiles in 25-cm vertical bins were provided by P. Howd (USF). The data provided by Elgar et al. resolve surface waves. Wave data provide more comprehensive comparisons, since waves have a known depth dependence and simple propagation characteristics. Surface wave variances can be interpolated/extrapolated over the whole domain surveyed by the PADS, permitting investigation of the time-space characteristics of the response.

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14. ABSTRACT

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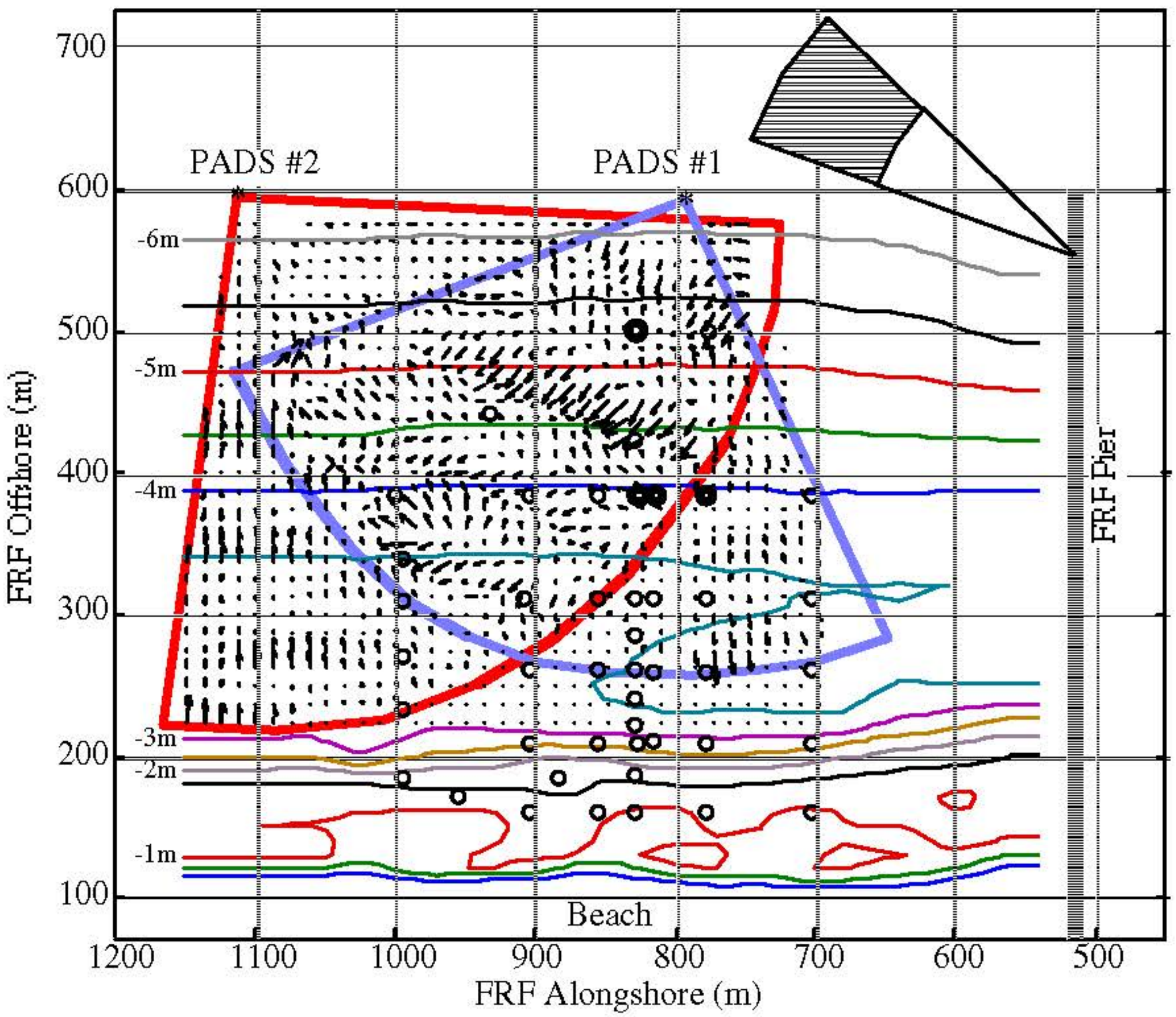

Figure 1. Area covered by "Phased Array Doppler Sonars" (PADS) in SandyDuck. Arrows plotted on a 12.5 m grid indicate PADS velocity estimates over the field of view, extending from about 100 to 500 m offshore by 400 m alongshore. Horizontal orbital velocities from swell dominate this snapshot, with a prominent wave crest running across the overlap region (the line of arrows pointing down and to the left). The longest arrows correspond to about 1 m/s. Both horizontal components are estimated in the overlap region, but only the radial component where data are available from just one PADS. The circles show locations of instrumented frames; heavier circles indicate locations where detailed data comparisons were between the **in situ** ***and PADS velocities (see figure 2). Also shown is an area covered by FOPAIR in 1994 (hatched pie extending from the pier; see Frasier and McIntosh 1996). (Location USACE Field Research Facility)***

WORK COMPLETED

In general correlations are high between PADS and *in situ* current measurements. In stratified conditions, correlations remain high between PADS estimates and profile data between 0 and 3 m below the mean surface, with maximum correlation about 1.5 m below the mean surface. This is consistent with the *a priori* estimate that the PADS respond to a roughly exponential distribution of bubbles with depth having about 1.5 m depth scale.

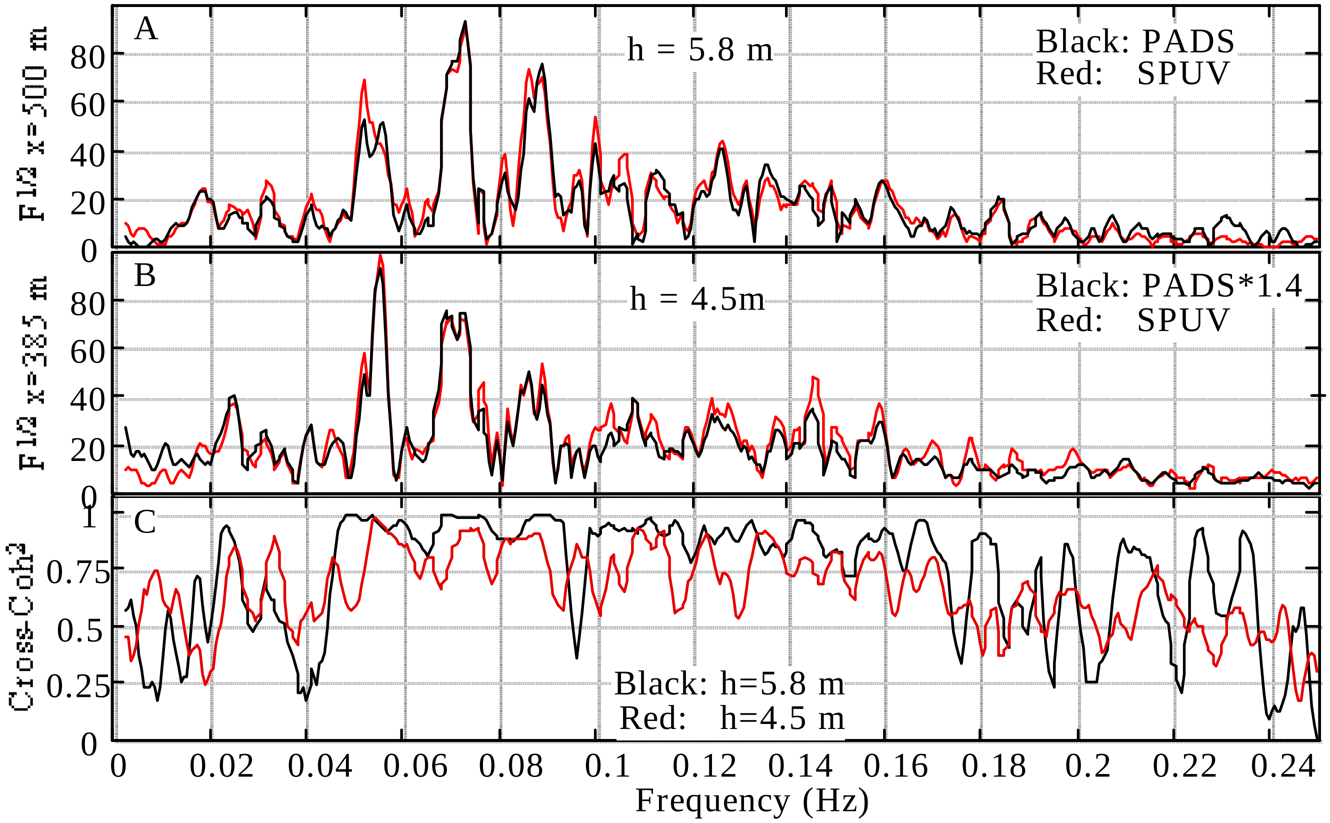

***Figure 2. Frequency spectra from PADS vs* in situ *current data (square-root of power density, m/Hz$^{1/2}$). (A, upper panel) At the deeper site (5.8 m deep) the spectra overlie with no amplitude discrepancy. Peaks are seen near 0.055, 0.07, and 0.9 Hz. (B, middle panel) At the shallower locations (4.5 m; three locations are averaged), the spectra overlie each other if the PADS values are increased by a factor of 1.4. Lower frequency peaks (e.g., 0.055 Hz) are enhanced more by shoaling than at higher frequencies. (C, lower panel). Spectral coherences between PADS and* in situ *data are high where spectral densities are high, ranging between 0.75 and 1.0 between 0.05 Hz and 0.17 Hz. At lower frequencies, stratification may reduce coherence due to the vertical separation of the PADS data (~1.5 m below the surface) and the* in situ *sensors (~0.5 m above the bottom). At the highest frequencies, coherence drops off due (most likely) to the finite averaging area inherent to the PADS data vs the point measurements made* in situ.**

Extensive comparisons were carried out over surface wave frequencies. The acoustic measurements are degraded near the current meter frames due to strong acoustic backscatter from the fixed structures, so the comparisons are actually made between measurements separated by about 15 m. The correlations between PADS and current meter data are comparable to those for two current meters separated by 15 m. Spectral coherences were computed between PADS and *in situ* data to investigate any frequency dependence. Wherever the spectral density is non-negligible, the coherences are high (figure 2). There is no noticeable trend with frequency.

The PADS-derived velocities are never larger than the reference data. This is consistent with a varying competition between volume backscatter (the desired signal) and bottom backscatter (having roughly zero Doppler shift). A simple acoustic model was developed to partition the received signal into bottom and volume contributions: the ratio of observed to "true" surface wave variance is used to

estimate the fraction of the signal coming from volume versus bottom backscatter. Rather than develop a complete wave propagation model, an approximate model incorporating finite depth dispersion, action conservation, and dissipation due to breaking [*Thornton and Guza*, 1986], but neglecting focussing (assuming the beach is uniform alongshore) was used. This "acoustic partitioning" is updated continually, based on velocity variance estimates formed over several minutes versus the inferred maps of the radial component of surface wave orbital velocities. This is described more completely in *Smith* [2001].

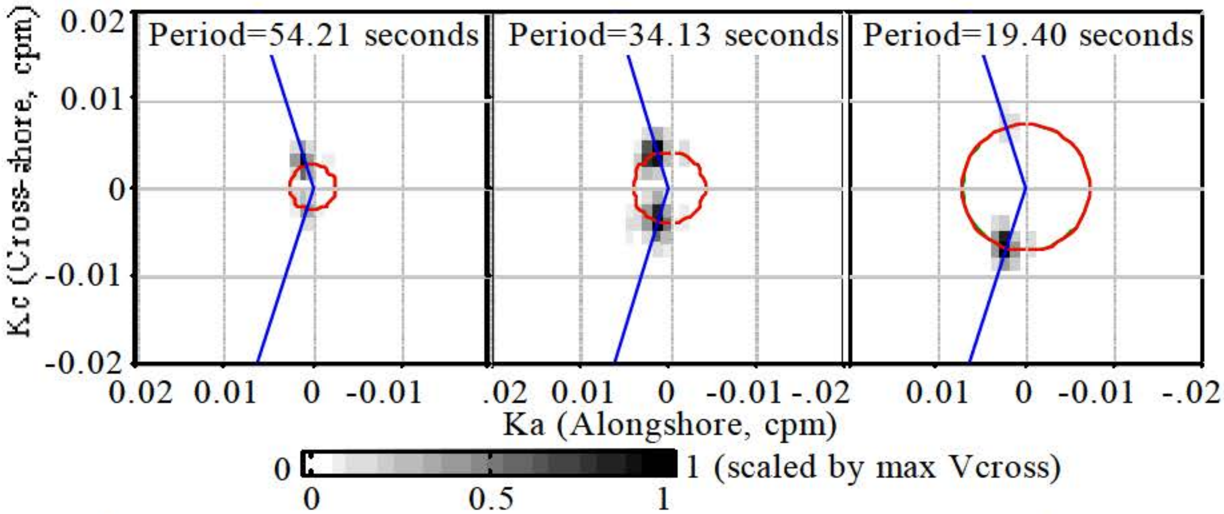

Figure 3. 2D wavenumber spectra for the cross-shore component of velocity at 3 frequencies: (left) 0.018 Hz, (center) 0.029 Hz, and (right) 0.052 Hz (spectral density relative to maximum in $(m/s)^2$ per $(cycle/m)^2$). The first two (left, center) are in the infra-gravity wave frequency band; the last (right) is at the lower-frequency swell peak. Lines radiating from the origin denote directions parallel to the swell peak direction (lower) or its reflection (upper lines). The infra-gravity peak directions align with the incident and reflected swell propagation directions. The incoming swell peak is larger than its reflection; at 34 s period incoming and outgoing peaks are roughly equal; at 54 s period the outgoing peak is larger. The circles correspond to linear dispersion which, at these frequencies, is at the shallow water limit, $(gh)^{1/2}$.

The dense array of measurements in space and time permit investigation of wave characteristics via direct 3D Fourier transform, as demonstrated previously with radar data [e.g., *Frasier and McIntosh*, 1996]. One way to view the results is in the form of wavenumber spectra at particular frequencies (see figure 3). Because the variation of depth over the sample area is not large, and because propagation varies only as the square-root of depth, the area can be treated as approximately uniform. An interesting observation is that infra-gravity variance appears to propagate largely parallel to the incoming swell or its reflection (figure 3). This may help in determining the generation mechanism(s) for the infra-gravity energy; this is being pursued in a work in progress.

RESULTS

- Comparisons between PADS and *in situ* current profiles support the *a priori* concept that the PADS respond to microbubbles concentrated near the surface, with an exponential profile having roughly 1.5 m depth scale.

- Surface wave characteristics may be used to deduce the division between volume backscatter (the desired signal) and bottom backscatter, extending the usefulness of the PADS measurements into calmer conditions, and providing calibrated estimates of velocity.
- Component velocities can be combined with good error estimates, making them ready for assimilation into models of the waves and currents near shore.
- Infragravity waves were observed that propagate predominantly in directions parallel to the incident swell and its reflection, supporting suggestions of a direct causal link.

IMPACT/APPLICATIONS

The PADS measurements are a natural complement to the discrete arrays of high-precision current meters, pressure sensors, (etc.) deployed within and near the surf-zone. With known performance characteristics, the dynamics of waves and currents, including radiation stress gradients and vorticity as well, may be pursued with more confidence (figure 4).

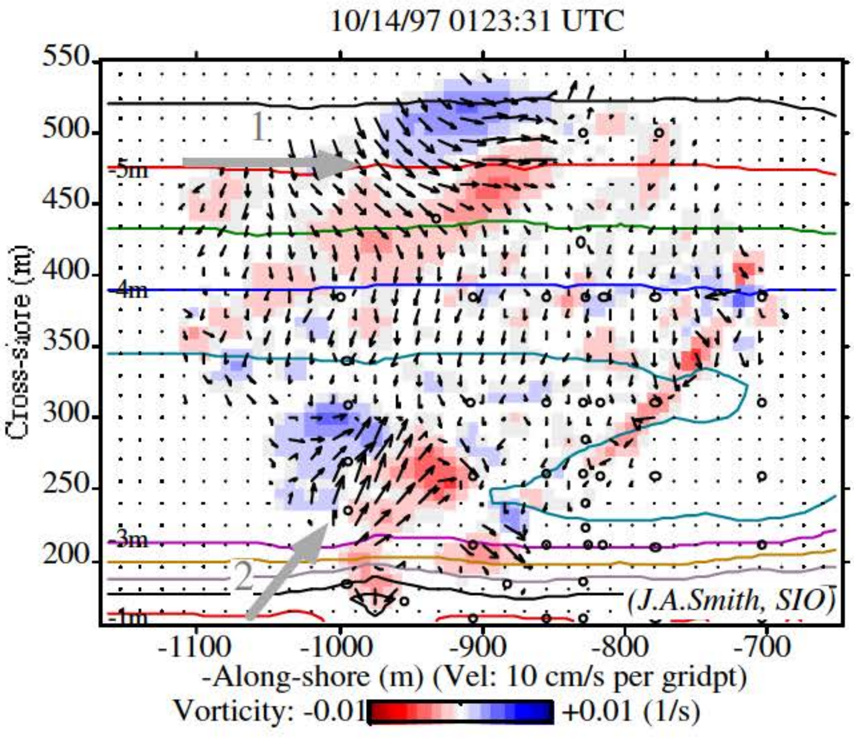

Figure 4. Two vorticity features observed with the dual-PADS. The upper feature (#1) resembles a vortex pair as is sometimes seen in models. This moves through the domain from left to right, along the trajectory roughly described by the gray arrow. The strength of the feature is fairly constant, and it appears to leave behind a trail of red (–) vorticity along the -4.5 meter depth contour. The lower feature (#2) is a rip current, probably originating near the gap in the sandbar. It propagates some distance into the domain, as suggested by the gray arrow, but then fades.

RELATED PROJECTS

Future projects include possible participation in an experiment focusing on waves and currents over the head of a submarine canyon (NCEX; proposal to NSF), and open ocean measurements of waves and Langmuir circulation in connection with gas exchange and wind stress estimates (planning stage).

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PATENTS

Paperwork toward patenting PADS technology has been registered.